

SECTION 3

METHODOLOGY FOR DEVELOPMENT OF CORRECTIVE ACTION OBJECTIVES, MEDIA CLEANUP STANDARDS (MCSs), POINTS OF COMPLIANCE, AND CORRECTIVE MEASURES ALTERNATIVES

The CMS Report provides the rationale for recommending the corrective measures that should be implemented at each soil and groundwater unit that requires remedial action. In order to accomplish this, Corrective Action Objectives and corresponding MCSs are first developed, which specify the required goals for protecting human health and the environment. The various corrective measures alternatives that have the potential for achieving the Corrective Action Objectives are then compiled and the alternatives recommended for implementation selected from the list of candidate alternatives through a formal evaluation process. To document that the Corrective Action Objectives have been achieved, compliance with MCSs will be demonstrated at prescribed locations in each environmental media requiring remediation.

3.1 CORRECTIVE ACTION OBJECTIVES

Corrective Action Objectives are the media-specific goals required to protect human health and the environment. Corrective Action Objectives were developed both to address potential risk and to address regulatory policy (i.e., the protection of the beneficial uses of groundwater). As described in Section 1.3.4, the ERA concluded that no hazards exist to plants or animals from exposure to chemicals in soil, groundwater, or surface water at Berkeley Lab (Berkeley Lab, 2002b). Therefore, no corrective action objectives were developed for ecological receptors. The human health exposure pathways and the corresponding receptors of potential concern were determined in the HHRA (Berkeley Lab, 2003a), and are listed in **Table 1.3.4-2** and **Table 1.3.4-3** for soil and groundwater units, respectively.

The primary Corrective Action Objective is to protect human health by reducing COC concentrations so that theoretical ILCRs are less than, or at the lowest reasonably achievable level within the USEPA target-risk range (between 10^{-4} and 10^{-6}) and HIs are less than 1. Based on the results of the HHRA (Berkeley Lab, 2003a), this objective is applicable to the following contaminant migration pathways.

- Inhalation of VOCs volatilizing from soil to indoor or outdoor air
- Inhalation of PCBs volatilizing from soil to indoor air
- Incidental ingestion and direct dermal contact with PCBs in soil
- Inhalation of VOCs volatilizing from groundwater to indoor air
- Dermal contact with VOCs in groundwater

The lowest reasonably achievable level within the risk management range was selected as the risk-based corrective action objective for the following reasons:

1. The USEPA has expressed a preference for cleanups achieving the more protective end of the risk management range (i.e., 10^{-6}) (USEPA, 1997).
2. The DTSC has also expressed a preference for the cleanup achieving the more protective end of the risk range (i.e., 10^{-6}), if reasonably achievable. The required cleanup levels will be specified by the Standardized Permits and Corrective Action Branch of the DTSC in a modification to Berkeley Lab's RCRA Hazardous Waste Handling Facility (HWHF) Permit.
3. Institutional controls will be required for those areas where the theoretical $ILCR > 10^{-6}$ and/or $HI > 1$.

In addition, the DTSC could initiate enforcement actions against Berkeley Lab, if RCRA CAP requirements specified in a modified HWHF Permit (including required cleanup levels) are not followed. Additional compliance and legal costs would likely be incurred as a result of such enforcement actions.

The following Corrective Action Objectives were developed based on regulatory requirements:

- Protect and/or restore groundwater quality to levels that are protective of beneficial uses (i.e., COC concentrations less than or equal to Maximum Contaminant Levels [MCLs] for drinking water in areas where groundwater meets SWRCB criteria for potential drinking water sources under Resolution 88-63
- Control the migration of contaminated groundwater so that COCs do not migrate to groundwater in adjacent uncontaminated areas or to surface water.

- Control the migration of contaminated groundwater so that COCs above risk-based levels do not migrate to groundwater in adjacent areas where concentrations are below risk-based levels.

These objectives were selected for the following reasons:

1. They are California state legal requirements specified in Resolutions of the SWRCB under the Porter-Cologne Water Quality Control Act (Division 7 of the California Water Code).
2. Institutional controls will be required in areas considered a potential drinking water source and MCLs are exceeded.

There are various costs and benefits associated with compliance or non-compliance with the risk-based and regulatory-based objectives listed above. Cleanup to less stringent risk based levels (e.g., 10^{-4} or 10^{-5} rather than 10^{-6}) would be less expensive and would still be in the range that is considered safe and protective of public health. However, lower cleanup levels would result in added costs for new building construction and possibly preclude development in some areas. Less stringent risk based levels would also adversely affect the project schedule and incur additional costs since they would require negotiation with the regulatory agencies. Non-compliance with the regulatory-based objectives could result in enforcement actions and resultant legal costs. In addition, there could be a possible impact on private property values in neighborhoods adjacent to Berkeley Lab.

3.2 MEDIA CLEANUP STANDARDS

Media Cleanup Standards (MCSs) are media-specific concentrations that the corrective measures must achieve in areas that currently exceed these concentrations, in order to meet the corrective action objectives. As described in the RCRA Corrective Action Plan (USEPA, 1994), MCSs “*must be based on promulgated federal and state standards, risk derived standards, all data and information gathered during the corrective action process*”, and/or other applicable guidance documents)....” The general methodology used to develop MCSs is described below. The specific MCSs proposed for COCs in soil and groundwater at Berkeley Lab are developed in Sections 4 (VOCs) and Section 5 (PCBs).

3.2.1 Risk-Based MCSs

Proposed Risk Levels

The proposed MCSs for Berkeley Lab are based on two criteria: 1) the USEPA-recommended target cancer-risk range for risk managers (i.e., a theoretical ILCR between 10^{-6} and 10^{-4}) also referred to as the “risk management range” and 2) a non-cancer hazard quotient (HQ) value (for individual chemicals) of 1.0. These ranges are consistent with the Corrective Measures Objectives described above. A target ILCR in the range of 10^{-4} to 10^{-6} is considered by the USEPA to be safe and protective of public health (Federal Register 56 [20]: 3535, Wednesday, January 30, 1991). An HI (sum of HQs) below 1.0 will likely not result in adverse non-cancer health effects over a lifetime of exposure.

An industrial/institutional land use scenario was used to develop risk-based MCSs, which is consistent with the current and potential future land use at Berkeley Lab. To help ensure that the corrective measures technologies selected are appropriate to the corrective measures objectives, and can result in the lowest reasonably achievable COC concentrations within the USEPA risk management range, DTSC has indicated that proposed target risk-based MCSs should be based on theoretical ILCRs of 10^{-6} (the lower bound of the risk management range).

Since the target risk-based MCSs may not be achievable at some groundwater units due to technical impracticability, upper-limit risk-based MCSs are also provided that represent the upper bound of the USEPA risk management range (i.e., a theoretical ILCR of 10^{-4}) and non-cancer HQ of 1.0. The upper-limit risk-based MCSs will be used to assess compliance with corrective measure objectives at locations where target risk-based MCSs cannot reasonably be achieved.

Modifications to the Human Health Risk Assessment Methodology

The proposed risk-based MCSs for Berkeley Lab were derived for an industrial/institutional land use scenario generally utilizing the same methodology and input parameters as were used to estimate risks in the HHRA (Berkeley Lab, 2003a). Toxicity values were first reviewed, however, to ensure that the most recently available toxicity data would be used in the MCS calculations. The following revisions in toxicity data were identified and incorporated into the risk-based MCS calculations:

1. Updates of the USEPA Integrated Risk Information System (IRIS) or National Center for Environmental Assessment (NCEA) toxicity values included:
 - Revision of the dermal reference doses (RfDds) for 1,1-DCE, 1,1,1-TCA, benzene, and TCE
 - Revision of the unit risk factor (URF) for ethylbenzene
 - Revision of the reference concentration (RfC) for n-butylbenzene.
2. USEPA IRIS or NCEA values were used for chronic reference exposure levels (RELs) in the HHRA since the California Environmental Protection Agency's (CalEPA's) RELs had not yet been adopted. RfCs for TCE, ethylbenzene, methyl tertbutyl ether, toluene, naphthalene, chloroform, methylene chloride and PCE were changed as a result of the newly adopted RELs.
3. The cancer risk factor for 1,1-DCE was withdrawn by USEPA, and 1,1-DCE is no longer considered to be a carcinogen by either the USEPA or Cal-EPA.

Although no revisions have been made to cancer risk factors for TCE, recent research on TCE carcinogenicity strongly suggests that the cancer risk factors used to estimate the risk-based MCSs for TCE are overly conservative by approximately a factor of 10. A discussion of this research is given in **Appendix A**.

The calculations used to determine the proposed risk-based MCSs are presented in **Appendix A**.

An additional modification to the risk assessment calculations was a change in the value for the building crack density parameter (η) used for indoor air modeling. The HHRA estimates for the risks to potential future indoor workers from the indoor air inhalation pathway were based on the American Society of Testing and Materials (ASTM) implementation of the Johnson and Ettinger (1991) vapor intrusion model (ASTM, 1995), using conservative ASTM default parameters to define soil and building physical characteristics. These default parameters are generally within the range of values possible for the physical properties of soil and overlying buildings at Berkeley Lab units, so they were also used for developing the risk-based MCSs for groundwater. However, for the potential future indoor worker pathway, the parameter (η) used to represent the proportion of floor area that consists of open cracks has a default value of 1%, which is considered to be unrealistically high for future buildings that might be located at the site. Based on this discrepancy, regulatory agencies using either the ASTM implementation, or

subsequent implementations, of the Johnson and Ettinger model have adopted lower values for this parameter.

- The City of Oakland Urban Land Redevelopment (ULR) program assigned a value of 0.1% to η for application to their implementation of the ASTM vapor intrusion model, based on California data presented by the American Society of Heating, Refrigerating, and Air Conditioning Engineering (Spence and Gomez, 1999).
- The USEPA has assigned default values of 0.38% for slab-on-grade houses and 0.02% for houses with basements for the current implementation of the Johnson and Ettinger model (USEPA, 2003).
- The RWQCB uses a value of 0.04% for all scenarios for current implementation of the Johnson and Ettinger model (USEPA, 2003).
- A comparison of indoor air results with soil-gas concentrations at Berkeley Lab Building 7 using the Johnson and Ettinger 1991 model suggested that 0.2% was a reasonable site specific value.

Based on this information, Berkeley Lab has adopted a value of 0.2% for η , which is between the values provided by the California-specific City of Oakland ULR program value and the USEPA value for slab-on-grade construction.

3.2.2 Regulatory-Based MCSs

The principal regulatory standards that may be pertinent to the development of MCSs at Berkeley Lab are provided in **Table 3.2.2-1**. These standards contain specific numerical requirements for allowable chemical concentrations in the affected environmental media (groundwater and soil) at Berkeley Lab.

Table 3.2.2-1. Regulatory Standards Potentially Pertinent to MCSs at Berkeley Lab

Standard	Description
<i>Federal</i>	
Safe Drinking Water Act (CFR40.141)	Sets Maximum Contaminant Levels (MCLs) and Maximum Contaminant Level Goals (MCLGs) for drinking water.
Toxic Substance Control Act - PCB (40 CFR Part 761)	Sets cleanup requirements for PCBs.
<i>State</i>	
California Safe Drinking Water Act (CCR Title 22, Division 4, Chapter 15)	Sets California Maximum Contaminant Levels (MCLs) for drinking water.
Porter-Cologne Water Quality Control Act (California Water Code, Division 7)	Adopts Water Quality Control Plans (San Francisco Bay Basin Plan) that establish beneficial uses of state waters and sets water quality objectives for those uses.

The regulatory agencies that implement the laws and regulations commonly adopt policies that guide their applicability and implementation. Potentially applicable policies that have been adopted by the SWRCB, the agency created by the Porter-Cologne Water Quality Control Act include:

- Resolution 68-16 “Statement of Policy with Respect to Maintaining the High Quality of Waters in California” (non-degradation policy) requires that for waters for which water quality objectives are set by Basin Plans or the Porter-Cologne Water Quality Control Act, existing water quality must be maintained. This resolution implies that non-detect or background levels must be maintained except in specific circumstances.
- Resolution 88-63, “Sources of Drinking Water Policy,” specifies that, except under specifically detailed circumstances, all surface waters and groundwaters are to be protected as existing or potential sources of municipal and domestic supply.
- Resolution 92-49, “Policies and Procedures for Investigation and Cleanup Abatement of Discharges under Water Code 13304”, requires regional boards to meet the highest levels reasonably obtainable, where, at a minimum, water quality objectives established in the Basin Plans must be met. However, it does permit specification of case-by-case cleanup levels where restoration of background levels is not a reasonable objective.

In addition, the RWQCB has prepared the technical document “Screening for Environmental Concerns at Sites with Contaminated Soil and Groundwater” (RWQCB, 2003). The document presents “conservative” Environmental Screening Levels (ESLs), which were developed to address environmental protection goals presented in the Water Quality Control Plan for the San Francisco Bay Basin (RWQCB, 1995). The ESLs are based largely on risk assessment modeling, similar to that presented in the Berkeley Lab HHRA, and modeling of soil concentrations that might impact groundwater as a potential drinking water source.

The California RWQCB San Francisco Bay Region’s Water Quality Control Plan (Basin Plan) (RWQCB, 1995) establishes beneficial uses and water quality objectives (WQOs) for groundwater and surface water in the San Francisco Bay region. The Basin Plan identifies existing beneficial uses of East Bay Plain groundwater as: Municipal and Domestic water supply; Industrial Process water supply; Industrial Service water supply, Agricultural water supply; and possibly Freshwater replenishment supply. Although Berkeley Lab is not in the East Bay Plain, some groundwater beneath Berkeley Lab may be a source of recharge for the East Bay Plain basin, so these beneficial uses may be pertinent to Berkeley Lab groundwater.

However, according to the RWQCB's review of General Plans for several East Bay cities, including Oakland and Berkeley, there are no plans to develop local groundwater resources for drinking water purposes, because of existing or potential salt-water intrusion, contamination, or poor or limited quantity (RWQCB, 1999).

SWRCB Resolution No. 88-63 specifies that all groundwaters of the State are considered suitable, or potentially suitable, for municipal or domestic water supply, with the following exceptions: 1) the water source does not provide sufficient water to supply a well capable of producing an average sustained yield of 200 gpd, 2) total dissolved solids (TDS) exceed 3,000 mg/L, or 3) contamination that cannot reasonably be treated for domestic use by either Best Management Practices or best economically achievable treatment practices.

Although groundwater is not used for drinking water or other beneficial uses at Berkeley Lab and is not used for drinking water downgradient in the City of Berkeley or at UC Berkeley, potential beneficial uses of groundwater at Berkeley Lab would include domestic supply, except for those areas where the specific exceptions to SWRCB Resolution 88-63 apply. Under the Basin Plan, cleanup levels "for groundwaters with a beneficial use of municipal and domestic supply are set no higher than Maximum Contaminant Levels (MCLs) or secondary MCLs"... "whichever is more restrictive; or a more stringent level based on a site-specific risk assessment." In areas of Berkeley Lab where the well yield is greater than 200 gpd, and TDS concentrations are less than 3,000 mg/L, MCLs are the regulatory-based MCSs for groundwater COCs, providing that they are achievable through Best Management Practices or best economically achievable treatment practices. Most of Berkeley Lab is underlain by fine-grained, low permeability sedimentary rocks in which groundwater well yields are substantially lower than 200 gpd, although a few areas where undulations in the upper surface of these strata are filled with permeable volcanic rocks or surficial materials (colluvium and artificial fill) have wells where yields can exceed 200 gpd. In Section 2.2 and Section 4, figures are included showing the areas where the groundwater does not provide sufficient water to supply individual wells capable of producing an average sustained yield of 200 gpd.

As noted by RWQCB, "groundwater conditions directly underlying specific areas may limit potential use as a municipal or domestic drinking water supply" (**Appendix J**). Therefore

for those areas of groundwater contamination where well yields are less than 200 gpd, risk-based levels are considered applicable and are proposed as MCSs, at least for the short term. However, it is acknowledged that the RWQCB designates all groundwater potentially suitable for municipal or domestic supply unless it has been formally de-designated. Therefore, the long-term goal for these areas would be to restore groundwater quality to the maximum beneficial use (MCLs), if practicable. Once the short-term goal is achieved, the long-term approach would be natural degradation within the framework of a long-term monitoring program to document the status of natural degradation and that migration of contaminated groundwater is under control. It is not possible to specify with a high level of confidence the timeframe when MCLs would be achieved in areas where the well yield is less than 200 gpd. Based on the very low rates of attenuation observed, it will likely take at least several decades to achieve MCLs in most of these areas. In the interim, groundwater will be monitored to document the status of natural degradation and assure that migration of contaminated groundwater is under control. Regulatory-based MCSs (MCLs) will not apply in those areas with insufficient well yield to be considered a potential drinking water source.

3.2.3 Regulatory-Based Compliance Levels

In addition to MCSs, a compliance level of non-detect was set for areas of groundwater and surface water that are not currently contaminated, but could potentially be impacted by migration of COCs. This compliance level addresses the SWRCB non-degradation policy under the Porter-Cologne Water Quality Control Act. In addition, the HHRA and ERA assumed that pathways from surface water to human and ecological receptors would remain incomplete, based on continued capture prior to the discharge of contaminated groundwater to surface water.

3.2.4 Costs Associated with MCS Levels and Compliance Levels

Cost estimates to achieve both risk-based cleanup levels and cleanup levels based on protection of potential future drinking-water sources are provided in Section 6.

3.3 DEMONSTRATION OF COMPLIANCE WITH MEDIA CLEANUP STANDARDS

Points of compliance are the site-specific locations at which the concentrations of individual COCs are measured and MCSs must be achieved. Points of compliance are established in each environmental media requiring remediation.

Groundwater

For groundwater, MCSs should be achieved throughout the area of contamination. This is referred to as throughout-the-plume/unit point of compliance (POC) for groundwater. Locations for demonstrating compliance with groundwater MCSs will consist of representative wells in the existing Berkeley Lab groundwater monitoring network. These wells will be located both in the area where groundwater MCSs are exceeded, and downgradient from those areas to monitor for downgradient plume migration. Some of these wells have been used to monitor the performance of ICMs or pilot tests, and will continue to monitor the performance of these systems if selected as a final remedy. New monitoring wells may be installed if required to monitor the performance of additional corrective measures that are implemented.

Groundwater monitoring at Berkeley Lab is currently based on a schedule (Berkeley Lab, 2001) that was approved by the RWQCB in 2002 (RWQCB, 2002). A revised monitoring schedule will be submitted to the RWQCB that establishes the requirements for compliance monitoring. Some wells that were installed for initial characterization purposes are now considered to be superfluous for monitoring compliance with MCSs or remedial system performance, and are recommended for abandonment. In addition, it is expected that the number of wells required for compliance monitoring and the required frequency of monitoring will decrease over time as more groundwater remediation progresses and the area where MCSs are exceeded becomes smaller. Groundwater monitoring wells that are considered superfluous will be identified as such in the Groundwater Monitoring and Management Plan or in other documentation submitted to the Water Board, and will be properly destroyed after receiving Water Board approval. Revised monitoring schedule requests will be periodically submitted to the RWQCB for approval.

When the concentrations of COCs in all compliance wells at a groundwater unit are lower than MCSs averaged over four consecutive quarters of monitoring, the corrective measure will be considered complete for that unit.

Soil

Compliance with MCSs at soil units will generally be demonstrated by collecting post-remediation samples representative of residual contamination. Prior to implementing a corrective measure at each soil unit, a workplan will be submitted to the DTSC that will include the requirements for collecting confirmation samples. The requirements will specify sampling locations for soil treated in place or provide the number of samples required per square foot of excavation wall and floor. For PCB remediation waste, a sampling grid of 1.5 meters, with a minimum of three sampling points is required (40 CFR §761.283). A smaller square grid interval can be used when the PCB-cleanup site is sufficiently small or irregularly shaped. For soils that are contaminated with VOCs, a larger-size sampling grid may be specified, with a minimum of one floor sample and one sample for each wall of excavation.

To demonstrate that remedial objectives have been attained, the MCSs will be compared to representative site chemical concentrations to which human receptors may be exposed (exposure point concentrations [EPCs]). In accordance with USEPA guidance (USEPA, 1989), the EPCs will be set for soil at the 95-percent upper confidence limit (UCL) on the arithmetic mean of the sample concentrations, unless the sample size is less than eight ($N < 8$) or the percentage of non-detect values is greater than 80%. In those cases where there are insufficient soil data to calculate a reliable UCL, the maximum concentration will be used. When MCSs are attained at the confirmation soil sampling locations, the corrective measure will be considered complete for that unit.

3.4 TECHNICAL IMPRACTICABILITY

Remediation of contaminated media to the prescribed MCS can in certain situations be technically impracticable from an engineering perspective. Technical impracticability (TI) for contaminated groundwater refers to a situation where achieving groundwater cleanup levels associated with final cleanup goals is not practicable from an engineering perspective (USEPA,

2001). The term engineering perspective refers to factors such as feasibility, reliability, scale or magnitude of a project, and safety.

The USEPA has noted that permanent reduction of VOC concentrations in groundwater below certain levels (e.g., to MCLs) cannot be achieved at many sites using currently available technology (USEPA, 2001). Currently, groundwater underlying approximately 3% of the total area of Berkeley Lab site exceeds MCLs, as illustrated on **Figure 2.2-1**. Reasons for the technical impracticability of groundwater cleanups are generally the result of hydrogeologic and/or contaminant-related factors, such as very low permeability soils and/or the presence of residual dense non-aqueous phase liquids (DNAPLs) (USEPA, 2001).

Low permeability rock and soil containing DNAPL or very high levels of dissolved VOCs are present at several of the Berkeley Lab groundwater units. These conditions limit the effectiveness of remedial technologies in attaining MCSs. The impact of these conditions is further compounded by geologic characteristics such as multiple layers, heterogeneities, and fractured rock, which are present over most of the site. In areas where DNAPL is present it constitutes a continuing source of dissolution of COCs into the groundwater that decreases the effectiveness of dissolved phase cleanup actions. The presence of low permeability rock and soil in the saturated zone results in very low rates of advection (flow) of contaminated groundwater, so that contaminant migration mechanisms may be dominated by diffusion (the movement of molecules from zones of high concentration to zones of low concentration due to the random motion of molecules and ions). Diffusion of contaminants is a relatively slow process that can limit the ability to achieve MCSs, and impact adjacent areas for many years. The inability to deliver treatment reagents or transport media (e.g., water) in low permeability soils is an additional factor that can prevent remedial technologies from being effective.

The time required to achieve MCSs in areas of low permeability rock and soil containing DNAPL or very high levels of dissolved VOCs is difficult to accurately estimate. This is because diffusion rates are difficult to estimate, and because cleanup rates also depend upon unknown factors such as the mass of contaminant released and the length of time the contaminant has been present in the subsurface. In addition, cleanup actions may result in

contaminant removal rates that tail off (reach asymptotic levels) at concentrations that may be significantly above MCSs.

Based on the evaluation of site-specific factors contributing to TI provided above, it is likely that MCSs, particularly the regulatory-based MCSs (i.e., MCLs), will not be achievable at all groundwater units. The areas subject to corrective measures can generally be divided into the following three categories, based on potential to achieve MCSs:

- 1) Areas where MCSs are unlikely to be attained. These areas are characterized by low permeability rock and soil where DNAPL and/or very high levels of dissolved VOCs are present and excavation is not a feasible alternative (e.g., areas at or adjacent to the source zone of the Building 7 lobe of the Old Town Groundwater Solvent Plume).
- 2) Areas where attaining MCSs is likely. These areas fall into two subcategories:
 - a) Areas with relatively high permeability rock and soil containing low to moderate concentrations of dissolved phase VOCs (e.g., the Building 52 lobe of the Old Town Groundwater Solvent Plume); and,
 - b) Areas with relatively low permeability rock and soil containing low concentrations of dissolved phase VOCs (not significantly exceed MCSs) that are amenable to natural degradation processes (e.g., the Building 69A Area of Groundwater Contamination).
- 3) Areas where the ability to attain MCSs is uncertain. These areas are generally characterized by low permeability rock or soil, the absence of DNAPL, and moderate to high groundwater contaminant concentrations (e.g., much of the Building 7 lobe of the Old Town Groundwater Solvent Plume).

Whether MCSs will be attained at a groundwater unit cannot be determined until sufficient data have been collected to determine contaminant reduction rates resulting from the implemented corrective measures, and how those rates change over time. The effectiveness of the implemented remedial technologies in achieving the required MCSs will therefore be evaluated in 2011 after five years of operation, or when sufficient data have been collected to support a Determination of TI. A Determination of TI requires approval of the DTSC. If the reviews show that groundwater concentrations are approaching an asymptotic level above the specified MCS (regulatory-based or target risk-based) and the mass of groundwater COCs being removed is not significant, then a Determination of TI will be requested from the DTSC. Each TI request will include the following components:

1. The specific groundwater MCSs, consistent with the groundwater use designations that are considered technically impracticable to achieve.
2. The area over which the TI decision will apply.
3. A conceptual model that describes the geology; hydrogeology; contamination sources, properties, and distribution; fate and transport processes; and current and potential receptors.
4. An evaluation of the restoration potential of the site, including data that support the conclusion that attainment of MCSs is technically impracticable from an engineering perspective.
5. Estimates of the cost of existing or proposed corrective measures.
6. A demonstration that no other corrective measures alternative would achieve the MCSs.
7. A proposed alternative remedial strategy protective of human health and the environment. The alternative remedial strategy would be considered protective of human health and the environment if the following criteria are met:
 - Concentrations of COCs are less than upper-limit risk-based MCSs or institutional controls are in place to block the exposure pathways of potential concern.
 - Institutional controls prohibiting future domestic use of groundwater are implemented for those areas where groundwater is a potential source of domestic supply.
 - If any remaining sources of contamination are still present, they are removed to the extent practicable.
 - The areal extent of the groundwater contamination is stable or decreasing.

3.5 SELECTION AND EVALUATION OF CORRECTIVE MEASURES ALTERNATIVES

3.5.1 Introduction

Corrective measures alternatives are intended to mitigate potential exposure to, control migration of, and/or remediate the COCs. A step-wise process was used to select and evaluate corrective measures alternatives for implementation at Berkeley Lab. The principal steps of the process were:

1. Identification of corrective measures alternatives that may be potentially applicable to specific classes of chemicals of concern (i.e., halogenated VOCs or PCBs) in the soil and groundwater at Berkeley Lab.
2. Preliminary screening of the potentially applicable alternatives, to reduce the large number of available technologies to a manageable number for more detailed evaluation

3. Evaluation of each corrective measures alternative using defined standards and selection factors
4. Recommendation of corrective measures for implementation.

3.5.2 Identification of Potentially Applicable Corrective Measures Alternatives

Corrective measures alternatives potentially applicable to each class of COCs chemicals-of-concern (solvent-related VOCs or PCBs) at Berkeley Lab were identified. For PCBs, potentially applicable remedial alternatives were developed primarily from USEPA guidance (USEPA, 1993a). For VOCs, the potentially applicable remedial alternatives were developed primarily from the Treatment Technologies Screening Matrix provided in the Federal Remediation Technologies Roundtable (FRTR) Remediation Technologies Screening Matrix and Reference Guide (http://www.frtr.gov/matrix2/section3/table3_2.html). In addition no action was included for both classes of COCs as a baseline for comparison.

The identified alternatives were classified into the following general corrective measure categories for both soils and groundwater:

- No Action
- Risk and Hazard Management
- Monitored Natural Attenuation
- Containment and Hydraulic Control
- Active Treatment/Disposal.

No Action

The no-action alternative includes no active remediation of COCs, but provides a basis for comparison with the other remedial alternatives. All previously implemented ICMs would be terminated, and no additional measures would be implemented except for institutional controls. Natural attenuation processes such as biodegradation, dispersion, adsorption, dilution, and volatilization would still occur; however, there would be no means to document the effectiveness of natural attenuation. The no-action alternative may be justified in some cases, especially where implementing a corrective measure will result in no significant reduction of risk to human health and the environment.

Risk and Hazard Management

Institutional controls are non-engineered instruments that help minimize the potential for human exposure to contamination and/or protect the integrity of a remedy by limiting land or resource (e.g., groundwater) use. They include administrative or legal controls, physical barriers or markers, and methods to preserve information and data and inform current and future workers of hazards and risks. Also included are operational safety requirements implemented to ensure worker safety and the proper handling of hazardous materials during remedial activities. Institutional controls are generally used when remedies are ongoing and when residual contamination is present at a level that does not allow for unrestricted use after cleanup. They are intended to supplement engineering controls and are rarely the sole remedy at a site.

Affected portions of Berkeley Lab land parcels subject to restricted use would be regulated through a Land Use Covenant (LUC) between UC and the DTSC, in accordance with California Code of Regulations (CCR), Title 22, Division 4.5, Section 67391.1. The LUC would not be a site-wide control, but would be placed on the individual parcels that are subject to land use restrictions. In areas where groundwater contaminant concentrations are less than regulatory-based groundwater MCSs (MCLs), no land use restrictions would be applicable based on groundwater contamination. In areas where groundwater contaminant concentrations exceed regulatory-based groundwater MCSs (MCLs), land use restrictions would be implemented as follows:

- Extraction of groundwater for domestic, industrial, or agricultural use would be prohibited unless it was treated to the required standards for domestic use; or groundwater concentrations could be demonstrated to be below levels of concern for industrial or agricultural use.
- Development of residential facilities would be prohibited unless subsequent site-specific studies documenting that risks to residential receptors were below levels of concern were submitted to, and approved by, the DTSC.
- Institutional land use would be permitted without restriction, except for areas where groundwater or soil contaminant concentrations exceed the upper-limit risk-based MCSs (i.e., theoretical $ILCR > 10^{-4}$, $HI > 1$).

For areas exceeding the upper-limit risk-based MCSs (i.e., theoretical $ILCR > 10^{-4}$, $HI > 1$), development of institutional facilities would be prohibited unless a mitigation and

monitoring plan was developed to ensure that COC exposures contributing to risks were below levels of concern. Mitigation and monitoring plans would be submitted to DTSC for review and approval.

Berkeley Lab will prepare a Groundwater Monitoring and Management Plan and a Soil Management Plan as part of the Corrective Measures Implementation (CMI) phase of the RCRA CAP. The groundwater monitoring and management plan will include: a description of the vertical and lateral extent of groundwater contamination; a listing of specific perimeter groundwater monitoring wells that will be used to monitor potential migration beyond current plume margins; a description of specific surface water monitoring requirements; and, a description of Berkeley Lab management controls that will be used to reduce potential risks from exposures associated with contaminated groundwater. The soil management plan will include a description of Berkeley Lab management controls that will be used to reduce potential risks from exposures associated with contaminated soil.

Monitored Natural Attenuation

The natural biodegradation of organic chemicals can occur when indigenous (naturally occurring) microorganisms capable of degrading the chemicals are present and sufficient concentrations of nutrients, electron acceptors, and electron donors are available to the microorganisms. Under favorable conditions, highly chlorinated hydrocarbons such as PCE, TCE, and 1,1,1-TCA will biodegrade to less chlorinated compounds (i.e., DCE, DCA and vinyl chloride) (**Figure 3.5-1**).

Microorganisms obtain energy for growth and activity from oxidation and reduction reactions (redox reactions). Redox reactions involve the transfer of electrons to produce chemical energy. Oxidation is a reaction where electrons are lost (from an electron donor) and reduction is the reaction where electrons are gained (by an electron acceptor). During natural biodegradation, a carbon source typically serves as the primary growth substrate (food) for the microorganisms, and is the electron donor that is oxidized. The carbon source can include natural organic carbon or anthropogenic (man-made) carbon such as fuel hydrocarbons. Electron acceptors can be elements or compounds occurring in relatively oxidized states such as oxygen, nitrate, sulfate, ferric iron, and carbon dioxide.

Natural biodegradation of organic compounds causes measurable changes in groundwater geochemistry. The indicator parameters of the redox reactions, including metabolic byproducts can be measured. The following factors indicate conditions favorable for biodegradation:

- Dissolved oxygen (DO) less than 0.5 mg/L
- Nitrate less than 1.0 mg/L
- Sulfate less than 20 mg/L
- Divalent manganese and ferrous iron greater than 1 mg/L
- Low values of the Oxidation-Reduction Potential (ORP).

Monitored natural attenuation (MNA) is the stabilization and long-term shrinking of a contaminant plume by natural processes such as microbial degradation. This alternative is generally applicable only to dissolved groundwater plumes. In order to implement this alternative, the source of the contamination must first be removed and the presence and rates of natural degradation processes must be documented. Natural attenuation processes can be demonstrated through a variety of lines of evidence, including static or retreating chemical isoconcentration contours over time, changes in the ratios of parent to breakdown products, the presence of bacteria capable of degrading the COCs, and/or the presence of geochemical indicators of naturally occurring biodegradation.

The major component of MNA as a remedial alternative would be the long-term monitoring program to provide initial and continuing confirmation that the predicted biological activity and/or reductions in COC concentrations occur and remain effective. Risk and hazard management measures may be required to protect human health and the environment during the long term until overall effectiveness can be achieved.

MNA is retained as a remedial alternative where natural degradation can be currently documented. MNA is also retained as an option for future consideration at other locations after the source has been removed and monitoring data indicate that natural degradation may be occurring.

Containment and Hydraulic Control

Containment and hydraulic control measures can be used to control the mobilization and migration of contaminants. For groundwater, this category primarily includes below-ground barriers

constructed to prevent further migration of contaminants, such as groundwater extraction trenches and wells, slurry walls, grout curtains, and permeable reactive barriers. These measures can also be implemented to control the migration of groundwater contaminants from source areas. Above-ground engineered covers (capping) and other containment measures (solidification and stabilization) can be used to minimize the leaching of contaminants from soil to groundwater.

Engineering controls can be used to eliminate, or reduce to acceptable levels, the potential risk to human health from processes such as COCs volatilizing from groundwater and migrating into the indoor air of new buildings. These controls could include vapor barriers or ventilation controls. Engineering controls may also be used to eliminate or reduce the potential for cross-media COC transfers or migration of COCs into less contaminated areas.

Containment and hydraulic control measures may be protective of human health and the environment; however, the time frame for contaminant reduction within the containment zone (i.e., upgradient of a below-ground barrier, or below an above-ground cover) would be significantly longer than more active remedial alternatives.

Active Treatment/Disposal

Remedial technologies consist of the direct application of methods that can be used to achieve the corrective action objective (i.e., attain the MCS) in each affected media. Instead of restricting the application of a technology to the edge of a containment zone (as in Containment and Hydraulic Controls, above), these approaches involve more active measures within the contaminant mass to ultimately provide attainment of MCSs throughout the unit. These remedial technologies are potentially applicable to both soil and groundwater media, and were selected from the following categories:

- In situ treatment
- Extraction/excavation with ex-situ treatment
- Extraction/excavation and off-site disposal.

3.5.3 Preliminary Screening of Corrective Measures Alternatives

The preliminary screening process consisted of an evaluation of the potential effectiveness and implementability of the identified corrective measures alternatives. Screening was performed for each of the categories of alternatives described in Section 3.5.2, and for subset technologies within each category, for each of the contaminant classes at Berkeley Lab. The screening was based on two general criteria: effectiveness and implementability.

- Effectiveness pertains to chemical-specific characteristics of technologies in reducing contaminant concentrations given the physical and chemical properties of detected COCs.
- Implementability pertains to site-limiting characteristics of technologies given the physical constraints of the site such as topography, building locations, underground utilities, available space, and proximity to sensitive operations and the characteristics of the affected media such as depth to groundwater and hydraulic conductivity.

Alternatives that did not pass this initial screening process were eliminated from further consideration.

3.5.4 Evaluation of Corrective Measures Alternatives

Each of the corrective measures alternatives that passed the initial screening process was then evaluated to determine whether it could meet the following four corrective action standards:

- Protects human health and the environment
- Attain MCSs
- Provides source control (if applicable)
- Complies with applicable standards for the management of waste.

Preference was given to those alternatives that could meet all four standards, or three standards where source control was not pertinent. At a minimum the alternative was required to be protective of human health and the environment and comply with applicable standards for the management of waste.

Protect Human Health and the Environment

Each corrective measures alternative was evaluated to assess whether it could effectively protect human health and the environment from unacceptable short and long-term risks either by meeting risk-based MCSs, or by eliminating exposure pathways to COCs exceeding risk-based MCSs.

Attain Media Cleanup Standards

Each corrective measures alternative was evaluated to assess whether it could potentially meet the proposed target MCSs. An alternative was assumed to meet this standard if the technology had been used effectively under analogous site conditions, and/or if the results of bench-scale testing, pilot-scale testing or ICMs indicated that the technology would be able to meet one or more of the MCSs. Both remediation of media with COCs exceeding MCSs, and prevention of COC migration into media where COCs are currently less than MCSs, were considered in evaluating this standard.

Provide Source Control

Where continuing releases from sources pose a threat to human health or the environment, source control technologies were evaluated to assess if they could provide either removal or containment of COCs that are available for dissolution into groundwater. An alternative was assumed to meet this standard if the technology had been used effectively under analogous site conditions, and/or if the results of bench-scale testing, pilot-scale testing or ICMs indicated that the technology would be effective in controlling the sources of contaminants.

Comply With Applicable Standards for Management of Wastes

Each corrective measures alternative was evaluated to determine the potential to produce manageable wastes. The regulatory standards pertinent to the management of wastes at Berkeley Lab are listed in **Table 3.5.4-1**.

Table 3.5.4-1. Regulatory Standards Pertinent to Waste Management

Standard	Description
<i>Federal</i>	
Resource Conservation and Recovery Act (40 CFR Parts 261 to 268)	Regulates waste treatment, storage, and disposal facilities and defines waste types.
Toxic Substance Control Act - PCB (40 CFR Part 761)	Establishes disposal options for PCB remediation wastes.
<i>State</i>	
CCR Title 23, Division 3, Chapter 15	Regulates water quality aspects of waste discharge to land.
CCR Title 22, Division 4.5, Chapters 11 and 12	Provides standards for the management of hazardous waste. Applies to excavated contaminated soil and spent GAC.

In addition, corrective measures for groundwater and soil may result in discharges to air and the sanitary sewer that are regulated by permit requirements. Regulations for emissions of treated soil gas from vapor treatment systems are enforced by the Bay Area Air Quality Management District (BAAQMD). Limitations for air discharges are specified in BAAQMD Regulation 8 Rule 47 (Air Stripping and Soil Vapor Extraction Operations). Regulations for the discharge of wastewater from groundwater treatment systems into the sanitary sewer are enforced by EBMUD. Berkeley Lab's Wastewater Discharge Permit provides the daily maximum allowable concentration for discharge to the sanitary sewer.

On-site reuse options were evaluated for treated groundwater when treatment systems were initially installed. Effluent from two treatment systems was used as makeup for cooling tower water at Building 88 and Building 37. The Building 88 reuse was halted when it was determined that the water was potentially damaging to cooling tower operations (total dissolved solids concentrations were too high). Reuse at the Building 37 cooling tower has continued. Currently, and according to the remedies proposed in this report, most of the treated groundwater will be recirculated as part of implemented corrective measures to flush contaminants from the subsurface. Other on-site reuse options for extracted groundwater will be reevaluated in the future, if the water is no longer needed for recirculation.

Corrective measures alternatives that meet the four corrective action standards listed above were also evaluated against the following five corrective measures selection factors:

- Long-term effectiveness and reliability
- Reduction of toxicity, migration potential, or volume of the COCs
- Short-term effectiveness, including the near-term risks associated with implementing the corrective measure
- Implementability
- Cost.